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Storage of Dry Shelled Corn in Farm-Type Bins

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INTRODUCTION

In normal times, the major part of the corn crop in the United States is stored and consumed on the farm, and until a few years ago little thought was given to carrying over a large reserve. With the inauguration of the Government corn-loan program there was a large increase in the stocks of corn carried as reserve supplies and in the length of time such stocks were held. On October 1, 1941, the carry-over of corn was 646,000,000 bushels as compared with a 1928–32 average of 163,000,000. Much of this surplus was stored in farm-type bins (fig. 1). This reserve contributed to the conduct of World War

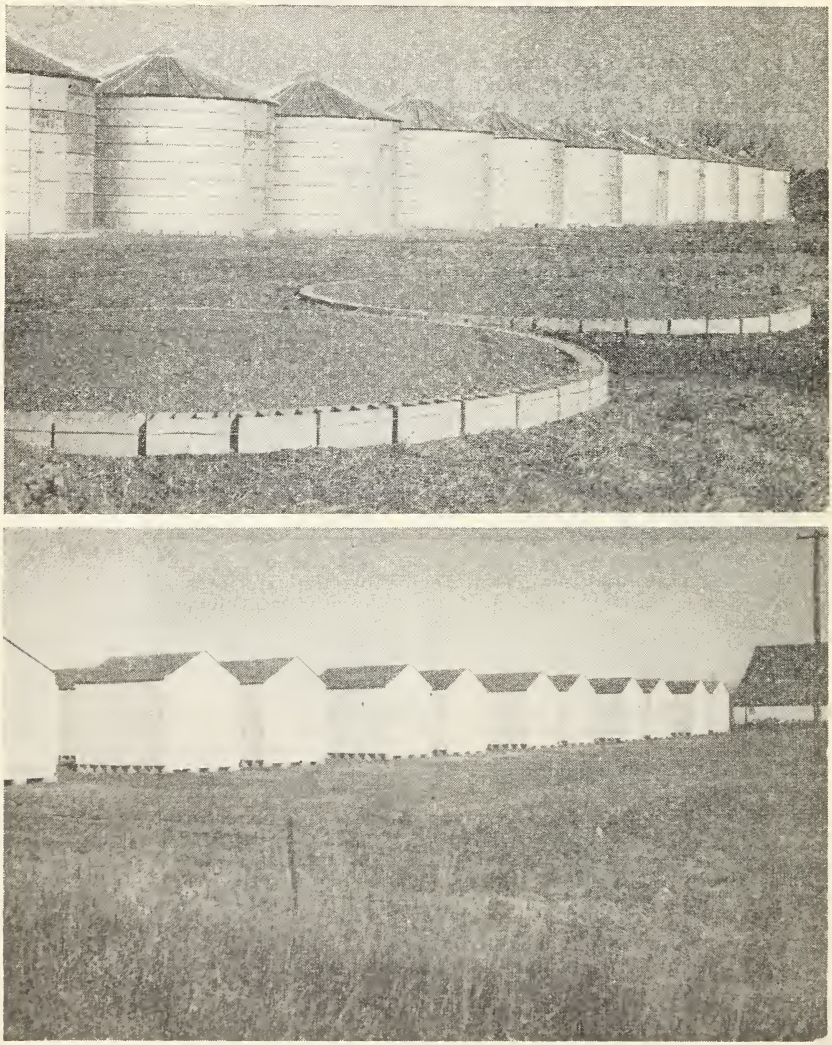

FIGURE 1.—Bins set up for the storage of shelled corn in the Corn Belt.

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II when unusually large supplies of grain were needed for expanded meat production and manufacture of alcohol for war uses. This contribution was in addition to the stabilization of feed and food supplies and market prices.

The purpose of this circular is to explain some of the problems encountered in long-time storage of shelled corn in farm-type bins and to state the conditions that are necessary for safe storage. It is based on observations relative to changes in moisture content, temperature, grade factors, germination, fat acidity, and insect infestation in Government-owned shelled corn stored in 140 bins at 17 bin sites in 5 States over a period of several years and on results of experimental storage of shelled corn in steel and wood bins in cooperation with the Iowa Agricultural Experiment Station at Ames, Iowa.

CONDITIONS NECESSARY FOR SAFE STORAGE OF SHELLED CORN

Experience in storing shelled corn and studies of mold growth [2] on corn have shown that 13½-percent moisture content is the maximum for safe storing through one season in the central part of the Corn Belt. A moisture content of 12 percent or less is highly desirable where corn is to be stored for more than 1 year, as the lower moisture content reduces the possibility of spoilage. If moisture content is not uniform throughout the bin, the wettest corn in the bin should not exceed these limits.

When grain is kept cool, there is less likelihood of spoilage. Low temperatures tend to offset the effects of high moisture with respect to both insect hazard and other deterioration, so that in cooler climates the moisture limits for safe storage are higher than in warmer areas. Insects differ greatly in their resistance to cold, and fortunately some of our worst pests are quite vulnerable to winter temperatures, especially in the portion of the Corn Belt north of latitude 42° (central Iowa and northern Illinois).

Cracked corn and foreign material provide favorable conditions for the development of infestations of "bran bugs," which breed with difficulty in clean grain. When going into storage, shelled corn should contain very little of such material, preferably below 1 percent, which should not be concentrated in small regions in the bin.

Ventilation of the space between the grain surface and the roof will be helpful in cooling and in removing excessive accumulations of moisture from the upper layers of grain. Ventilation that provides for movement of air through dry shelled corn is not necessary to keep the corn in good condition, and in fact such ventilation, if continuous, would be detrimental because, except in periods of low humidity, the corn would absorb some moisture from the air. Forced ventilation to cool the corn early in the winter, as discussed on page 19, may be beneficial.

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[2] SEMENIUK, G., NAGEL, C. M., and GILMAN, J. C. OBSERVATIONS ON MOLD DEVELOPMENT AND ON DETERIORATION IN STORED YELLOW DENT SHELLED CORN. Iowa Agr. Expt. Sta. Res. Bul. 349, pp. [254]–284, illus. 1947.

Bins for Storing Dry Shelled Corn

Floors must be strong enough to support the weight, and walls must be strong enough to withstand the outward and downward pressures of the grain. In addition to having ample structural strength, a bin must be constructed so as to prevent increases in moisture content or other changes in condition of the corn. Bin walls, roof, and floor must be tight to prevent the entrance of moisture. Experience has shown that the entrance of rain or snow into stored corn has been a major cause of storage difficulties. Even where dry shelled corn is stored, a roof or wall leak will cause some corn to spoil completely. This not

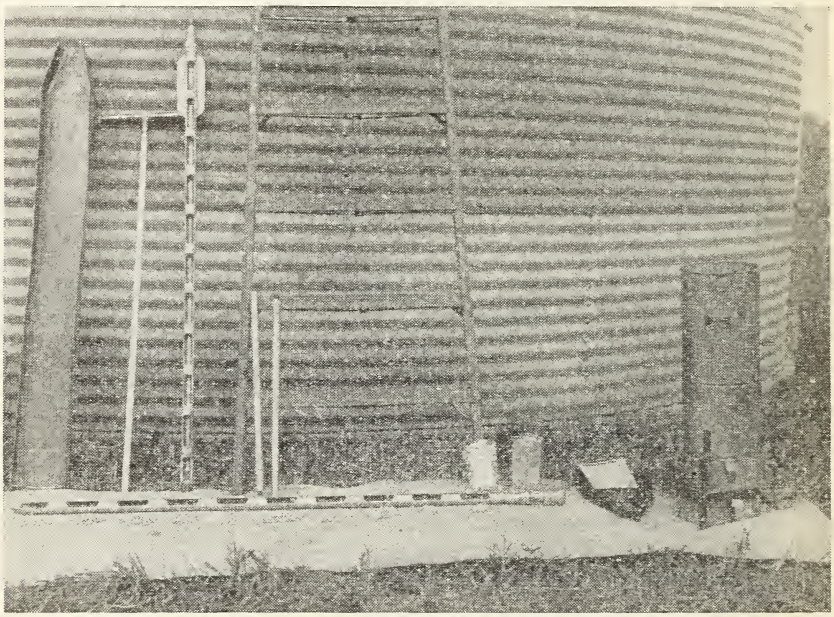

Figure 2.—Equipment used in inspecting and sampling stored shelled corn. The 5-foot probe with extension pipe handles is used for deep sampling of bins. The "trough" or the canvas is used for receiving samples direct from the probe; the sample divider for accurately dividing a sample into smaller representative portions. The airtight metal containers and cellophane bags are used to hold or ship samples.

only makes some of the adjacent corn musty, but contributes also to development of insect infestations. Tight walls and floors are highly desirable for effective fumigation.

Provision for sampling and inspection of stored corn is desirable so that increases in the moisture content or development of insect infestation can be detected. The simplest method of getting a sample for inspection is to use a grain probe (fig. 2). Roof manholes and removable ventilator covers in steel bins with conical roofs provide access for probing. Most gable-roof structures also provide the necessary space. Bins with shed roofs often do not have sufficient space for adequate inspection.

Periodic Inspection

Frequency of sampling will depend upon the condition of the corn and the climate. Corn with 12 to 13 percent moisture should be sampled at least twice each year—once during February or March and again during the summer. Samples taken during the winter from the upper 5 feet near the bin center will give a good indication of the condition of the grain. Samples obtained during the summer from the bin center and the southern portions of the bin will generally be sufficient to detect any deterioration or insects within the grain mass.

Corn with moistures above 13 percent should be sampled more frequently while corn below 12 percent should require but one sampling per year, preferably in the latter part of the summer.

Frequent inspections of grain surfaces will disclose any surface molding or caking before serious spoilage has occurred.

Steel Bins

An inspection of a large number of empty steel bins (fig. 3) previously filled with shelled corn furnished an opportunity to determine the amount and causes of spoilage. None of the types and makes of steel bins inspected was entirely free of leaks. Leaks were also observed in bins erected with more than the usual care in making them tight. Careful attention should be given in erection to make bins as nearly leakfree as possible.

All of the inspected bins contained spoiled corn varying in amount from a trace to about 17½ bushels. The average was about 4 bushels per bin.

Leaks around emptying doors and doorframes were common to nearly all bin types and were responsible for spoiled corn ranging up to as much as 12 bushels per bin. The emptying door on the 2,740-bushel steel bin was responsible for some damage in nearly every bin of this type inspected (fig. 4). Even when calking compound was used there was often leakage between the doorframe and the wall. Damaged corn was also found on the floor in front of the door. The channel that forms the top member of the doorframe is not welded to the side members of the frame, and water that runs out of the end of it can run down on the inside of the side members of the frame and enter the bin between the inner panel and the doorframe.

Leakage around the door was also common in the bins with full-sized doors. Calking the junction of the doorframe and the wall helped, but did not prevent all leakage. Some water entered between the door and the doorframe because the drip cap above the door was not adequate.

Roof leaks were serious only in those bins where the roof anchor straps were attached in such a manner that the bolt holes in the roof were above the stored grain (fig. 5). Lead washers correctly applied provided a watertight seal. Where lead washers were omitted or had broken or where bolts were not tightened properly, leaks occurred and resulted in considerable spoiled corn.

Wall leaks were not responsible for any large quantities of spoiled corn. The leaks were generally due to imperfectly formed wall

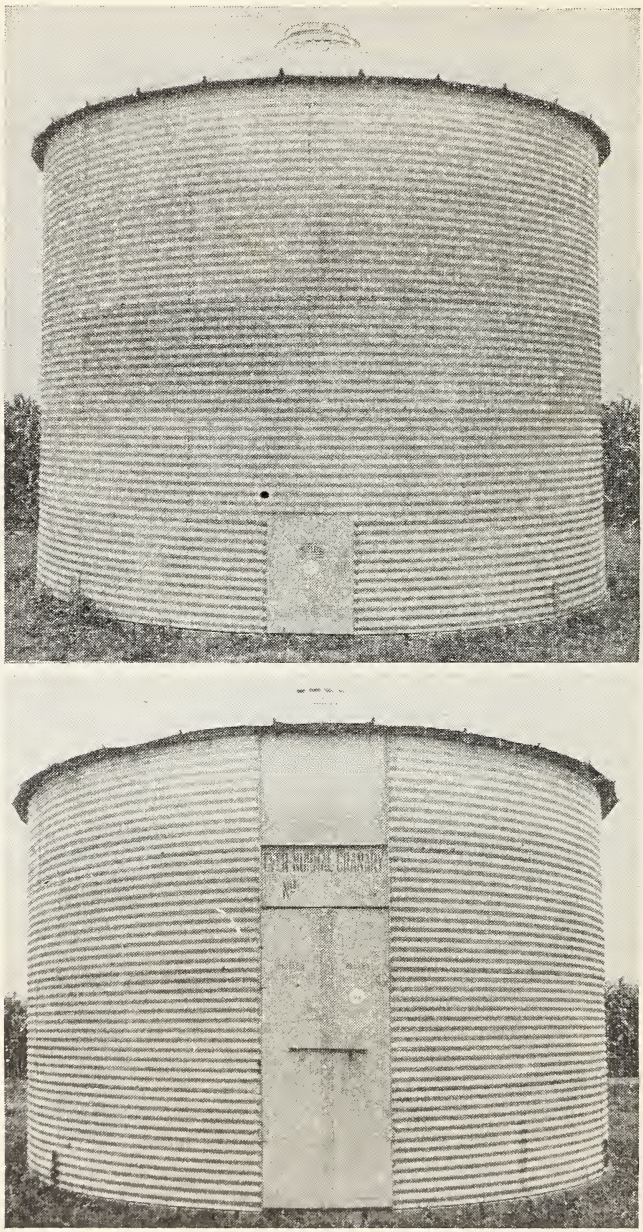

FIGURE 3.—Circular steel bins. Upper, 2,740-bushel bin: diameter 18 feet; height 13 feet. The lower ring of wall sheets is 18-gage corrugated galvanized steel; the other four rings are 20-gage. The floors are made up of 14 sections of 24-gage galvanized sheets with locking joints. A door 2 by 2½ feet is provided for emptying. Lower, 2,170-bushel bin: diameter 18 feet; height 11 feet. The wall sheets are 20-gage corrugated galvanized steel. The floors are similar to those in the 2,740-bushel bin. A full-size door is provided for entrance and emptying.

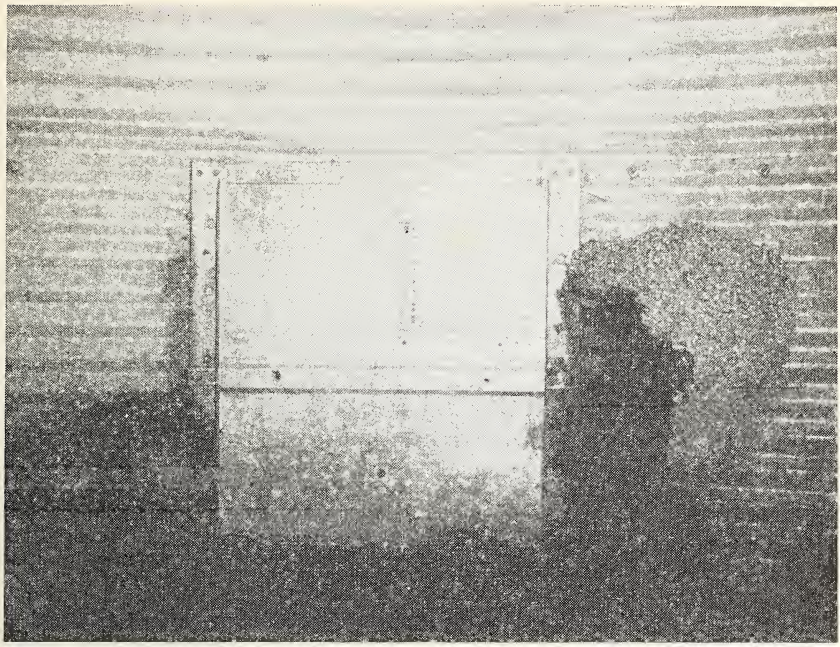

FIGURE 4.—Spoiled corn resulting from leaks around the emptying door in the 2,740-bushel circular steel bin. Inside view.

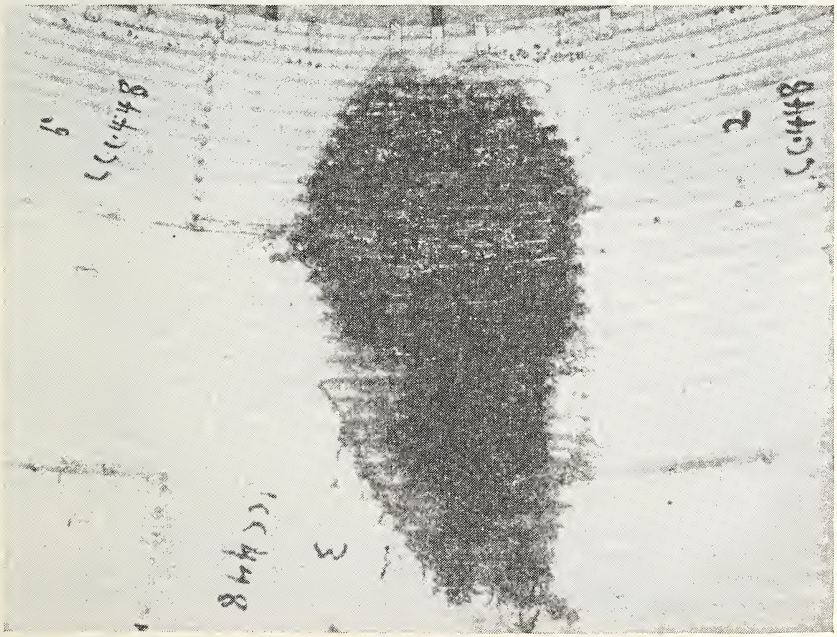

FIGURE 5.—Wall stains from roof leaks in circular steel bins where the hold-down straps were attached in such a way that the bolt holes in the roof were above the stored grain. Spoiled corn covered the stained areas before the bin was emptied.

sheets, improper tightening of bolts, omission of lead washers, or inadequate calking around bolts and at joints. In certain bin designs it is difficult to make joints tight enough to exclude moisture (fig. 6). Over 75 percent of the bins of this type were found to have leaks around the bolts in the joint of the wall sheets. It was difficult to tighten these bolts sufficiently to prevent leakage, even where lead washers were used. Even a slight loosening of the bolts or movement of the sheets when filling allowed moisture to enter around the bolt heads into the bin.

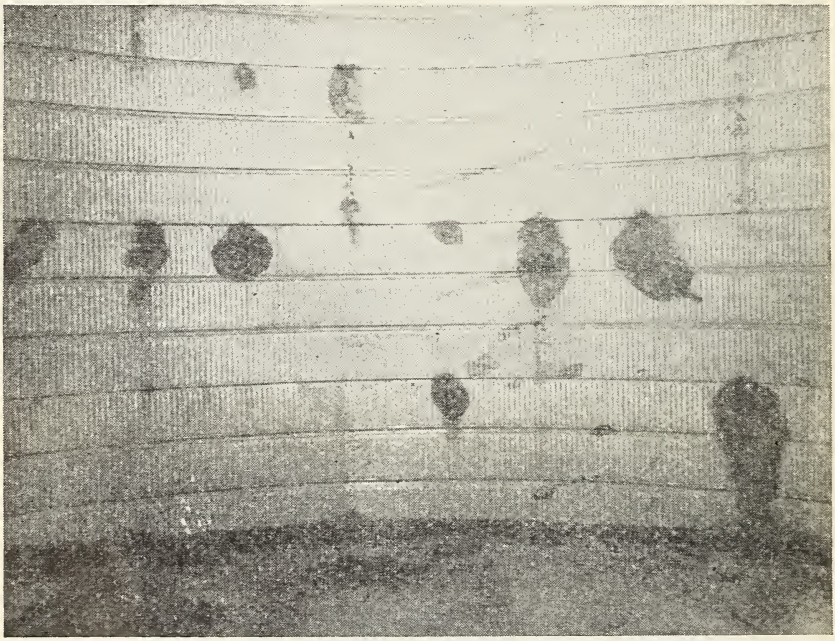

FIGURE 6.—Stains on walls of circular steel bins caused by leaks around bolts in the horizontal joints of the wall sheets. Spoiled corn covered the stained areas before the bin was emptied.

Faulty junctions between wall and floor were found in a number of bins but accounted for only a small part of the spoilage. However, depressions in the floor caused by settling of the floor fill retained moisture entering at the floor wall joints and increased the damage.

Many of the inspected bins showed no evidence that joints or bolts had been calked. Calking applied to vertical and horizontal joints, to door and wall junctions, to floor and wall junctions, and around bolts, aids in excluding moisture. This calking can best be done during erection of the bins; however, calking applied after the bins have been erected and filled will help to exclude moisture.

Some 1,000- and 2,000-bushel steel bins were lacking in strength around the manhole in the roof. The sag in the sides of the manhole allowed snow and rain to blow in. An economical method of remedying this fault is to bolt a 2- by 2-inch wood strip to each side of the manhole (fig. 7). While not as strong as steel angles, the wood

braces are lower in cost and make possible the desired snow tightness. The expense of reinforcing steel bins that are weak at this point is well justified.

Steel bins should be well anchored to prevent them from being blown from the foundation or upset while empty. Omission or improper installation of anchors resulted in a number of bins being blown from their foundations and partially or totally wrecked. Wind damage to bins almost always starts with the bin first sliding on its foundation, followed by its tipping over. Any method of anchoring

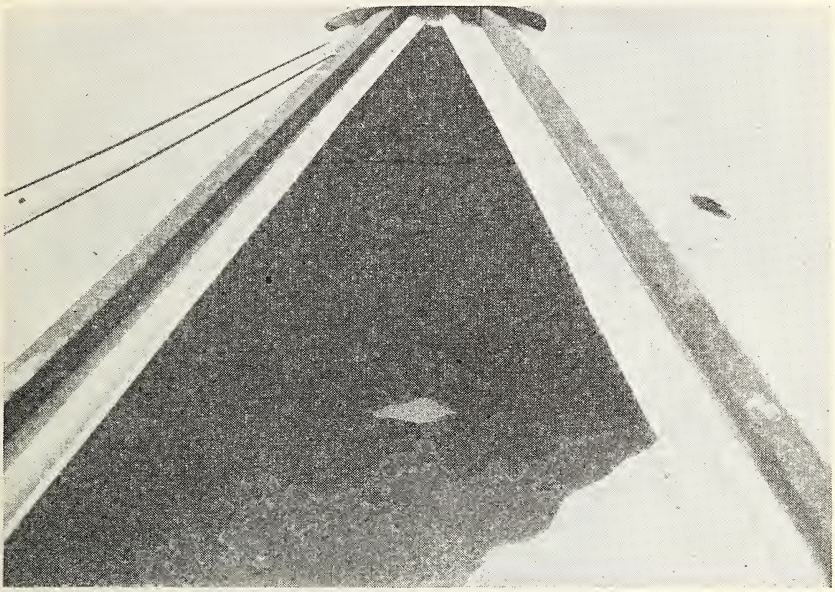

FIGURE 7.—Wooden rails are applied along the manhole opening to provide additional strength and stiffness and a tighter fit for the cover. Note the small pile of snow which has blown through the ventilator opening. Roof and ventilator tightness are important in excluding snow and rain.

should be planned to prevent this from taking place. Two methods of anchoring steel bins are shown in figure 8.

In most of the bins made prior to 1947, some changes in design and construction would be desirable to give added tightness. Suggested changes, applicable to some bins, are:

1. Eliminate roof hold-down straps attached to flat area of roof panels between panel joints (fig. 5).
2. A type of junction between wall and floor that would prevent water from entering.
3. Reinforced roof manhole for additional weathertightness (fig. 7); fastening of manhole cover also needs improvement for easier entrance.
4. Roof ventilators should permit tight enough closing to prevent entrance of appreciable amounts of snow.
5. Door assemblies, including bin boards, drip caps, sills, and attachment of doorframe to wall sheets, should be made more weathertight.

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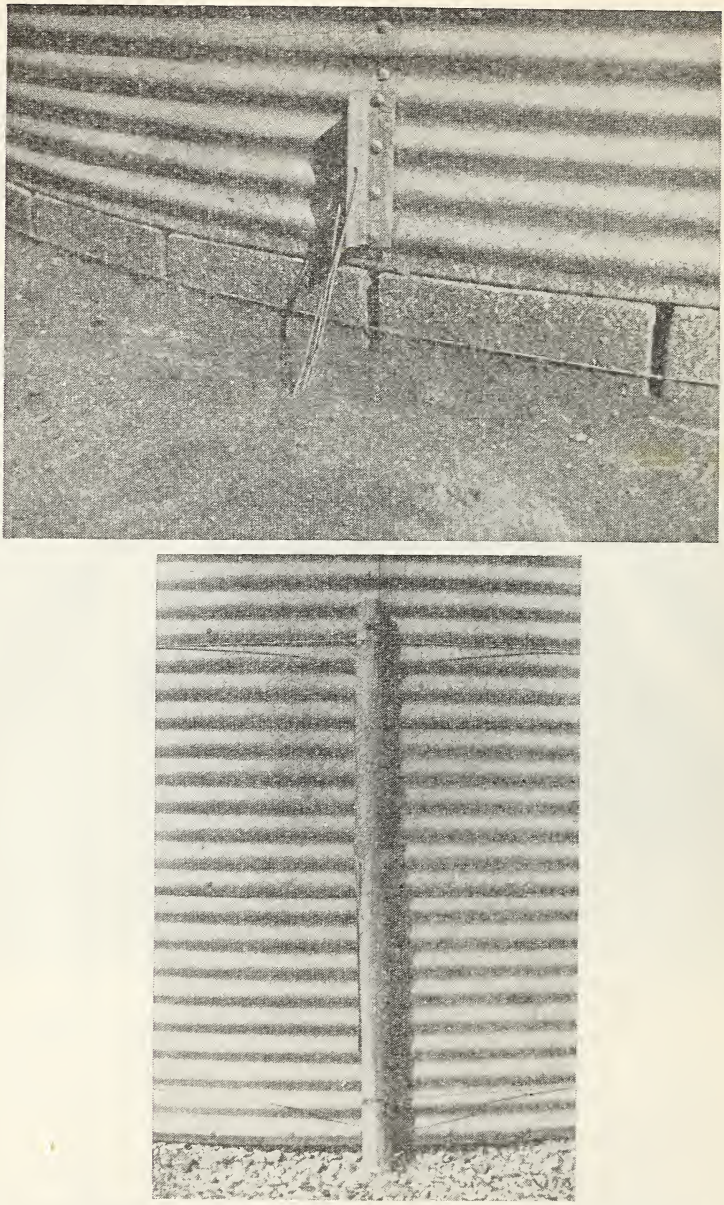

FIGURE 8.—Two methods used for anchoring steel bins. Upper, anchor bars are firmly attached near the bottom of the bin wall at four points. Galvanized No. 9 anchor wires are fastened to a "deadman" set from 2 to 3 feet into the ground and 3 to 4 feet out from the bin wall. Lower, treated posts at least 4 inches in diameter are set from 2½ to 3 feet into the ground and extend about 4 feet above the ground. The posts are bolted to the bin. Two strands of No. 9 galvanized wire are placed around the bin, one near the top of the post and the other near the bottom of the bin.

Wood Bins

Wood bins have long been used for storage of dry grain, including shelled corn. They are satisfactory if weathertight.

Few of the bins observed having single walls of matched lumber (fig. 9), were found to have the desired weathertightness for safe long-time storage (fig. 10). Use of low grade and green lumber contributed to the difficulty. Weathertightness can be obtained by the application of a second layer of material. Shiplap or matched boards

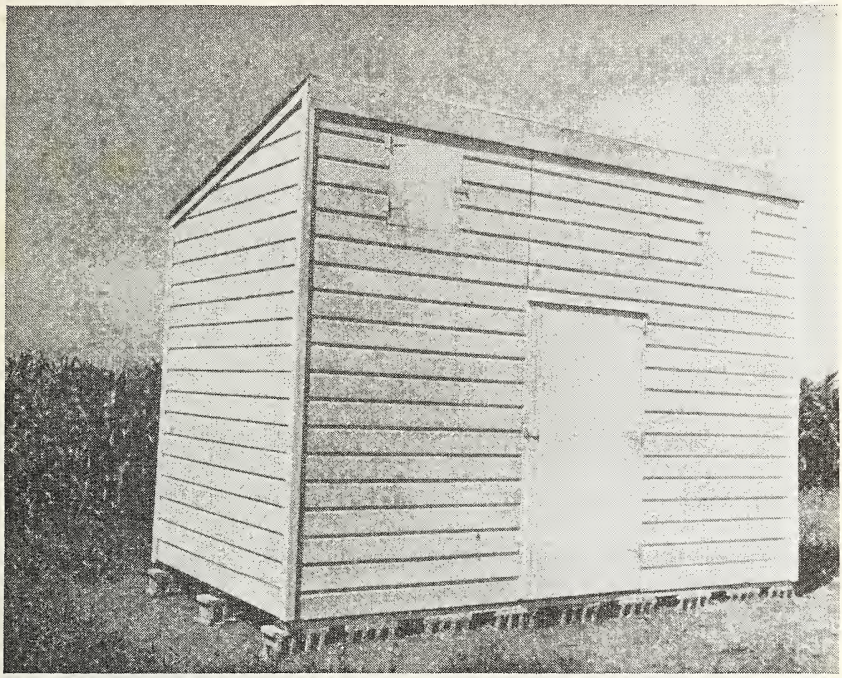

Figure 9.—Prefabricated sectional wood grain bin having single walls of matched lumber. Both flat- and gable-type roofs were used. Capacities for the various types ranged from 600 to 2,800 bushels.

may be applied inside the studding with matched siding applied outside. Another satisfactory wall is made by applying sheathing plus lap siding outside the studding. Other materials such as tempered hardboard, cement asbestos board, exterior plywood, metal sheets, and mineral-surfaced asphalt siding may be used. Lapped, or otherwise waterproof, joints must be used. Calking of butt joints has not proved effective.

Flashing at doorframes and other openings and use of drip caps and beveled sills at doors are necessary to exclude moisture.

Several different types of bins were designed for use in storing large quantities of wheat in 1942, and these can be used for storing dry shelled corn. Circular plywood bins with a capacity of 2,250 bushels were used (fig. 11). Where plywood of exterior grade could

FIGURE 10.—Damaged caked corn found on single-walled wood bin after 26 months' storage. The use of low-grade, green lumber for the bin walls contributed much to this condition.

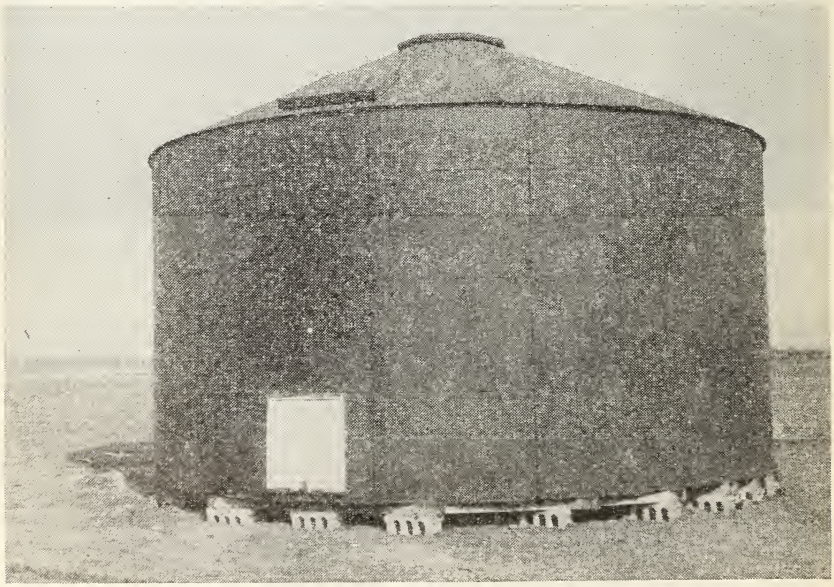

FIGURE 11.—A circular bin with plywood walls and roof. All joints were glued and the walls and roof covered with roll roofing to give weather protection. Steel bands around the bin give added strength. Diameter, 19 feet; height to eave, 10 feet, capacity, 2,250 bushels.

not be obtained a concrete-form plywood was used for the walls and roof of the circular bin. This plywood was protected against weather by the application of 35-pound smooth-surfaced roll roofing glued to the walls and roof panels with hot asphalt. Because of a number of failures of the circular type, light-weight steel bands were supplied for added strength. These bins, when covered with rolled roofing and strengthened with steel bands, furnished satisfactory storage for a period of a year or longer. Experimental rectangular plywood bins with no horizontal butt joints in the side walls and all vertical joints well stripped furnished satisfactory storage for a period of 2 years.

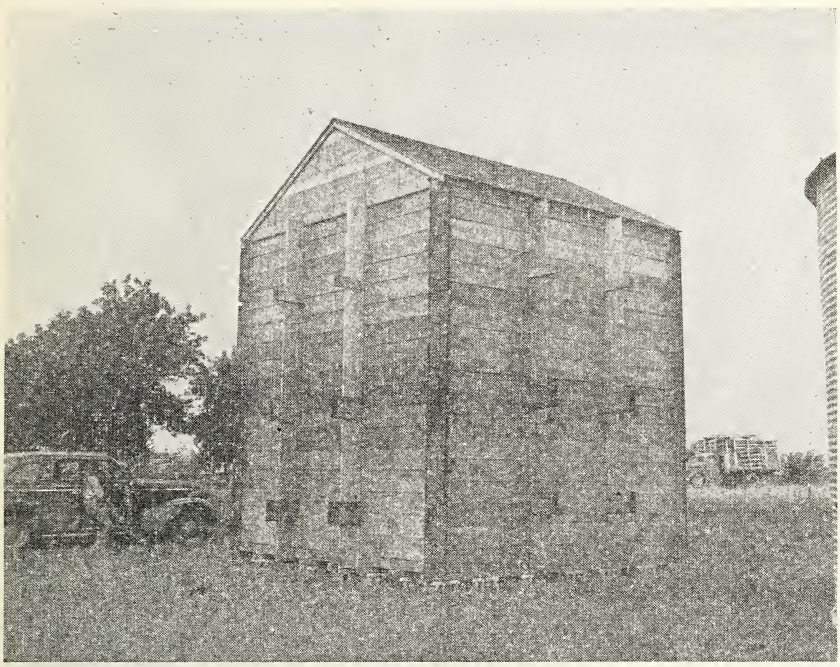

FIGURE 12.—A bin of tongue and grooved wood planks. Notched horizontal ties and uprights provide the strength to support the stored grain. Nails are required only for roof and floors. Dimensions, 14 feet 9 inches by 14 feet 9 inches by 17 feet. Capacity, 2,950 bushels.

A wood bin made of 2-inch lumber fastened at the corners through simple notches was economical and satisfactory except for leakage at corners and braces (fig. 12). This difficulty has been largely overcome by improvements in design. Horizontal ties and uprights provide the strength necessary to resist the pressure of the grain. This design permits the use of green lumber, since any shrinkage in the joints is overcome by settling of the walls, especially when the bin is filled with grain. The planks in this bin can be readily salvaged for other uses.

A number of bins were also constructed of ⅜-inch insulation board. Their low cost compensated in part for the weakness of the material and lack of resistance to shock and penetration. Steel bands were supplied to take care of the hoop tension.

A good foundation is essential and should be substantial enough to support the load in the storage structure. At least 1 square foot of footing should be provided for each 50 bushels of shelled corn. On poor soil, larger footing area may be required. Such temporary foundations as masonry, wood blocks, or logs need to be checked occasionally to make sure they are in condition to maintain the load of corn. Wood sills over concrete blocks should be arranged as shown in figure 13.

Moving or Turning Corn

If corn begins to heat, some conditioning can be obtained by moving it either by hand or by an elevator. Usually very little drying is accomplished by simply taking it from one bin to another. Moving, however, mixes the drier with the damper grain, as all the grain in a bin rarely begins to heat at once. The mixing by such turning, accompanied by the small amount of cooling and drying, is often sufficient to arrest heating. Corn containing much excess moisture, however, may require moving several times to reduce the moisture content as much as 1 to 2 percent. In view of the cost of turning and the relatively small drying effect, it should be considered only as an emergency measure. (See Appendix, p. 32.)

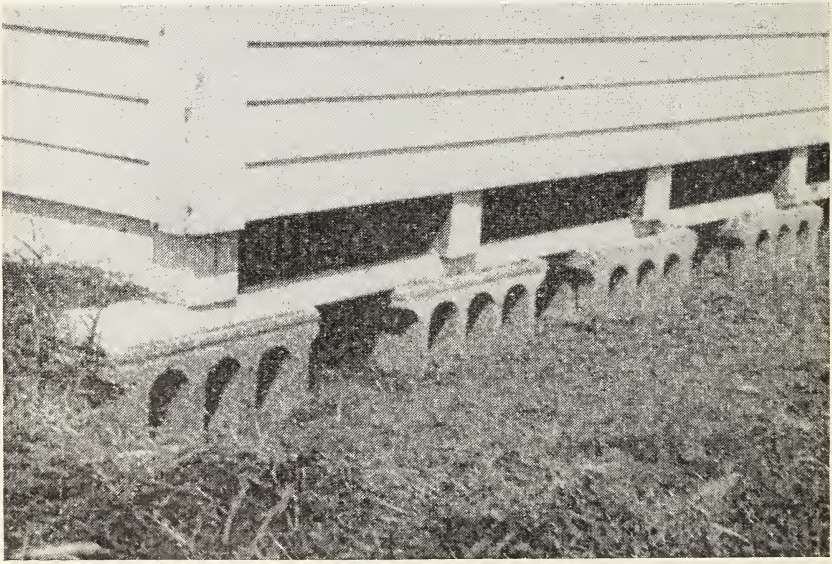

Figure 13.—Concrete blocks set at right angles to the floor joists to prevent tipping of blocks and joists. Two-inch stringers equalize the load. Openings in blocks are placed horizontally to give better bearing surface between blocks and earth.

Methods of Handling

Corn bins are usually filled with portable elevating equipment, unless the bins are located in a combination crib and granary. Flight, drag, or chain-type portable elevators are commonly used for handling shelled corn. Practically all the damage occurring with this type of elevator takes place in the sprockets at the discharge end. For this reason, provision is generally made for discharging through an opening in the trough ahead of the sprockets. Chain speeds from 100 to 175 feet per minute are generally used, but manufacturers' recommendations should be followed for best results.

Bucket elevators are generally used where permanent installations are made in combination cribs and granaries. These elevators cause little damage to the corn if manufacturers' instructions for installation and bucket speed are followed.

Two types of blower elevators are made for handling grain. One type is similar to ensilage elevators. The grain comes in contact with the blower blades. Some grain is always broken and this type should not be used where grain is to be stored for long periods. The other type, less commonly used, feeds the grain into the air stream above the fan. If conveyor tubes are smooth and turns in tubes are long, there is minimum breakage.

Auger types of portable elevators (fig. 14) are available for handling small grains. These may be used for loading and unloading grain from bins and trucks. They are built to handle grain at a rate of 300 bushels per hour and up, depending on the diameter of the auger and the angle of operation.

Much the same type of equipment is used for unloading shelled corn bins. Auger-type conveyors have been developed for use in conveying the corn from the bins to the elevator with little scooping. Scrapers or drags, operated by a power-driven drum or pulled by car or truck, expedite the unloading of bins and save hand scooping. Use of these devices helps to reduce the labor of handling the grain.

CHANGES IN CONDITION IN LONG-TIME STORAGE

Observations have shown that shelled corn may be stored successfully for at least 4 years, provided (1) all the corn has a moisture content not greater than 12 percent when stored, (2) the corn is kept relatively free from insects, and (3) the bin is effective in excluding moisture from the outside. After several years of storage in steel bins, the top layer of corn about a foot thick in the central area of the bin is in the poorest condition, largely because of an increase in moisture during the fall and winter seasons. (See pp. 17–19.)

Changes in Grade

Periodic inspections of Government-owned corn in steel bins from 1939 to 1943 showed the condition of the corn to be generally good over the entire commercial corn area. In most bins the average grade after 2 to 4 years of storage was No. 1 or No. 2. There was very little increase in the amount of damaged kernels other than in the upper layers and at points where bins leaked rain water into the grain. This

FIGURE 14.—A portable elevator of the auger type which may be used for loading and unloading grain from bins and trucks.

experience indicates that any changes that may occur in dry corn over a period of 4 years do not seriously reduce its commercial grade. Other measures of value of the grain, for feeding or processing, have not been developed completely. Small amounts of inferior grain are frequently detected by a determination of grade factors and special analyses such as fat acidity [3] and germination on "spot samples," even though the average grade remains unchanged.

Feeding Value

Experiments conducted by the Iowa Agricultural Experiment Station between November 1941, and July 1942, indicate that shelled corn stored up to 4 years in a dry condition and fed with the usual supplements had not lost value as a livestock feed. Stored corn grown during the 1937, 1938, 1939, and 1940 crop years, furnished by the Commodity Credit Corporation, and new corn from the 1941 crop were used for the feeding trials. Rates of gain of weight by steers getting undamaged corn were not influenced by length of storage or the crop year. The older corn was as palatable to the steers on feed as was the 1941 corn. The selling price of the steers when marketed, and other slaughter data, showed that the steers fed the stored corn were on a par with those fed the corn from the new crop as far as condition was concerned.

Loss of Germination and Increase in Fat Acidity

In general, the germination percentage decreased gradually throughout the period of observation. The decrease was very slight, except in upper layers of corn and in bins having high-moisture corn. In eight typical 2,740-bushel steel bins there was an average loss in germination, from September 1940 to April 1942, of only 5 to 7 percent at the centers near the floor and midheight in the bins. These bins were filled in 1940 with 1938 and 1939 crop-year corn and were located at various points in the commercial corn area. During the same period the loss in germination in the corn 6 inches below the surface at the bin center (where moisture content was highest) amounted to 50 to 60 percent.

Increases in fat acidity in general were in line with the decreases in germination. In the same eight bins the average increase in fat acidity was about nine units in the corn 6 inches below the surface, while 4 feet above the floor the increase averaged only slightly more than one unit.

Redistribution of Moisture

The storage of shelled corn for several years has provided opportunities to observe moisture changes in the corn in different parts of the bins. Aside from moisture increases resulting from leaks in bin

[3] The fat acidity determination is a chemical test based upon the amount of free fatty acids in the corn. The number of fat acidity units is the number of milligrams of potassium hydroxide required to neutralize the free fatty acids in 100 grams of corn. New corn may be expected to have fat acidity of less than 20 units. An increase to 40 units indicates appreciable deterioration.

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walls and roofs. higher moisture contents resulted from one or more of the following causes: (1) Redistribution of moisture. (2) heavy insect infestation. and (3) absorption of moisture from the air in damp weather.

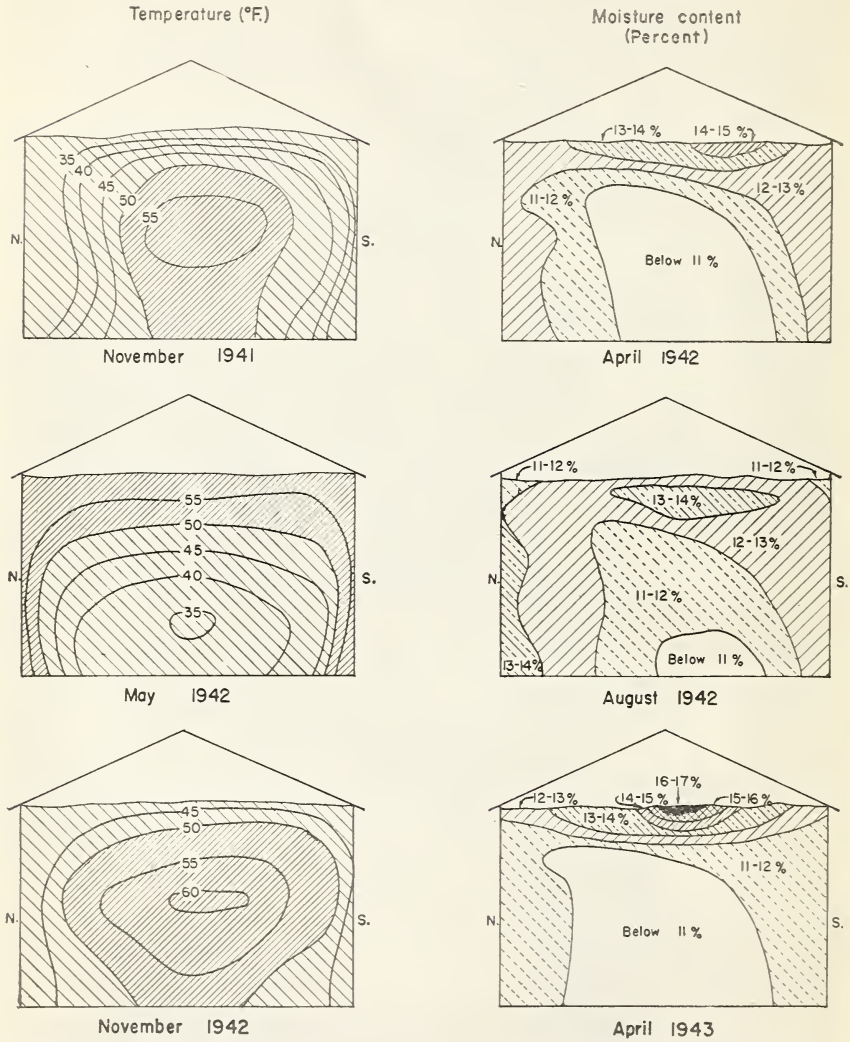


FIGURE 15.—Redistribution of moisture in 2,000-bushel steel bins at Ashton, northwestern Iowa. The corn temperature differences within the bin cause a convection movement of air through the grain mass. This air movement causes the moisture migration and accumulation illustrated on the right.

The redistribution of moisture in a 2,000-bushel steel bin is illustrated in figure 15. During the fall and winter the outer and top layers cool faster than the corn in the center of the bin. During November, for example, temperatures throughout the central part of the

bin were as much as 20° higher than those near the outer layers of corn. These temperature differences cause a convection movement of air within the grain mass which carries water vapor from the warmer grain to the cooler upper layers where it condenses. Migration of moisture is often responsible for considerable accumulation in the upper part of the bin, as in that shown in figure 15, where increases of 4 to 6 percent developed from August to April. The damp grain often found in the upper part of the bin is due largely to moisture migrating from other parts of the bin and not to moisture absorbed from the air. This moisture accumulation in the upper layers during the fall and winter is often responsible for some damaged grain. The amount damaged, however, is generally not over 5 to 20 bushels.

During the spring and summer the temperature pattern within the grain mass changes, with the outer layers warming faster than the central portions. The moisture movement then is in an opposite direction, but to a lesser degree, and not sufficient to prevent some spoilage in the upper layer in the center of the bin. The amount of moisture movement to the upper layers has been reduced in experimental bins by cooling the corn in the bin by forced ventilation with cold air during a cold period in the fall or early winter. In addition to reducing moisture migration, early cooling of the corn would be of some value in insect control. It is questionable, however, that these benefits are sufficient to justify the cost of power ventilation.

TEMPERATURE OF SHELLED CORN IN STORAGE

It is a well-known fact that grain in storage will heat if it contains excess moisture. The higher the moisture content the more rapidly it will heat. In this condition it will soon deteriorate, unless the heating is arrested by some means such as cooling or drying. Dry shelled corn will not heat in storage. However, temperature rises up to 105° F. due to heavy infestations of stored-grain insects have been observed. Such rises in temperature in themselves have not been found to be harmful to dry grain.

Even in the storage of dry grain, low temperature is desirable. The chances for deterioration, even if slow, as revealed by loss of germination and increase in fat acidity, will be reduced if lower temperatures are maintained. In the winter, if grain is cooled sufficiently, many of the common insects will be exterminated. In the summer or early fall, unless an appreciable amount of corn is at a temperature above 70° F. for more than a month, insects will not multiply sufficiently to present a storage problem.

Seasonal Variation

The temperature of shelled corn stored in 1,000- to 3,000-bushel bins changes slowly except for the layers next to the bin wall and at or near the surface. Changes 2 to 3 feet from the wall or below the surface can hardly be detected within a day, even with changes as high as 30° F. in atmospheric temperature. However, the average temperature of a bin of corn changes considerably throughout a season, as shown by the temperatures taken several times during a year. The

average grain temperature in a 2,740-bushel bin in central Iowa for the period September 1941 to March 1943 is shown in figure 16. The average temperature rose to a high of 70° F. in September 1941 and dropped to 30° F. in March 1943. The highest average monthly air temperature for the same period was 74° F. in July and the lowest, 24° in January. The lowest temperature of the corn was not reached until about 2 months after the air temperature had reached its mini-

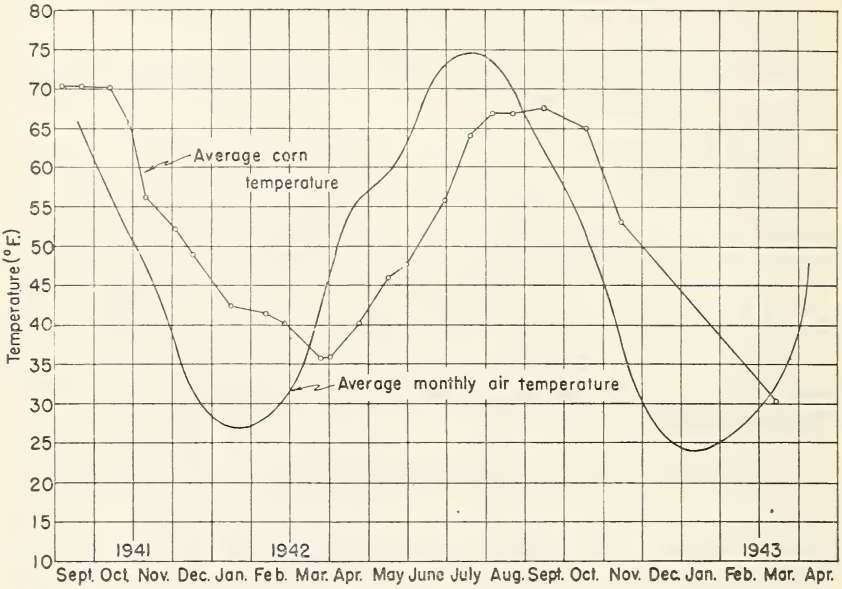


FIGURE 16.—Average corn temperatures observed in a 2,740-bushel circular steel bin at Ogden, central Iowa, during the period September 1941 to March 1943.

mum in January. The highest bin temperature occurred 2 months after the highest air temperatures. That is, the average temperature of the corn in the bins lagged about 2 months behind the average air temperature.

VARIATIONS OF TEMPERATURES WITHIN THE BIN

The discussion above dealt with the average temperature of the corn in the bin. However, temperatures are never the same in all parts of the bin, as may be noted from the temperatures shown in each of three representative bins in figure 17 at four different times during a year. These temperatures were taken in a north-to-south plane. In September, when the average temperature of the grain is the highest, the highest temperatures are in the upper part of the bin and next to the walls. The lowest temperatures are near the floor in the center of the bin. This is well illustrated by the bins in Illinois and Iowa, but not by the one in South Dakota. In the latter, the temperatures were taken nearly 2 weeks later and cooling had progressed much further due to the cool nights early in the fall.

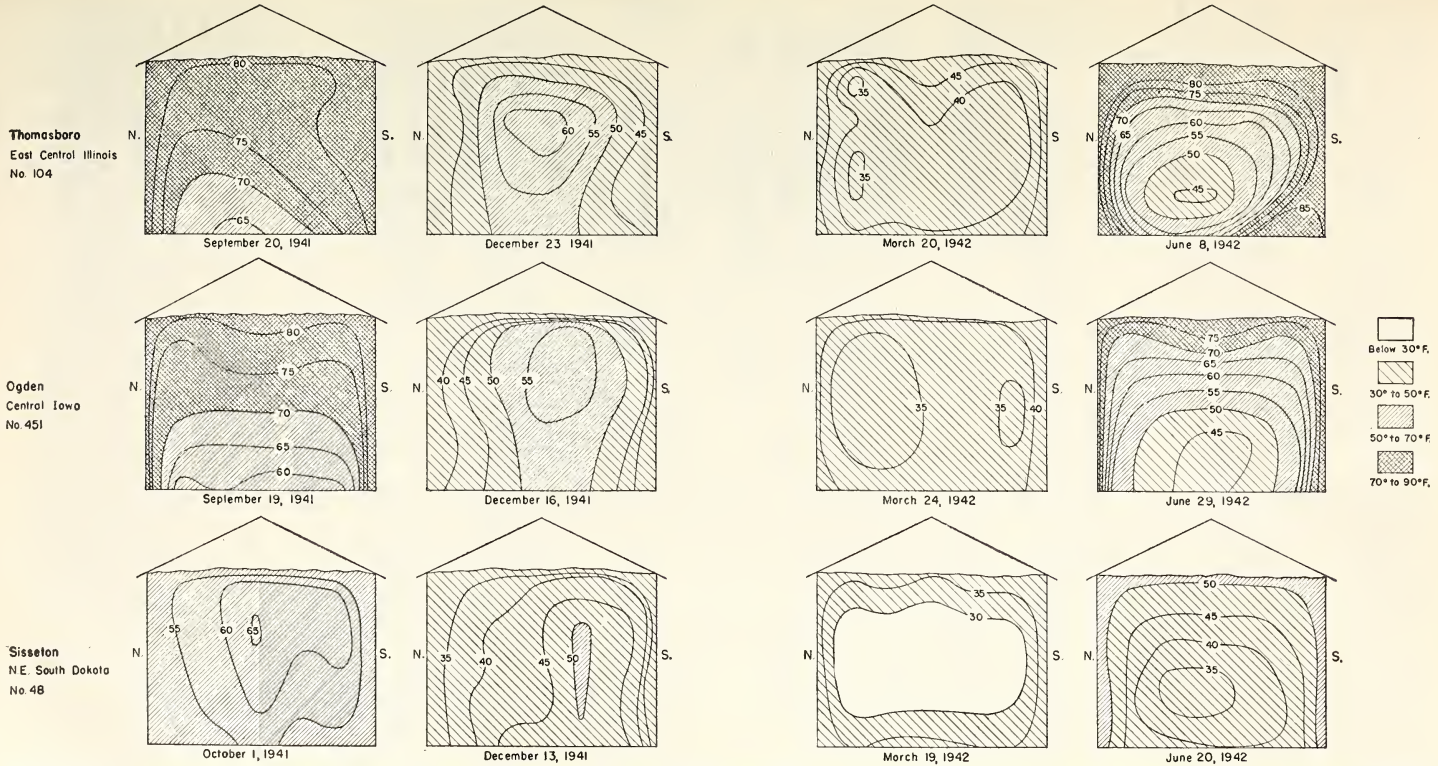


FIGURE 17.—Corn temperatures through the north-south vertical cross section of three 2,740-bushel steel bins located in different sections of the Corn Belt. These diagrams emphasize the temperature variations within each bin, the seasonal differences, and the effect of geographical locations on grain temperatures.

In December, when considerable cooling of the bins had taken place, the highest temperatures were in the center of the bin and the lowest next to the walls and the upper surface. Also, more of the warmest grain was in the south half, which shows the influence of exposure to the sun.

In March, when the average temperature of the grain was lowest, there was very little difference in temperatures in different parts of the bin. The greatest differences were only 5° to 10° F. In June, during the warming-up period, differences as high as 40° F. occurred between the cool grain in the center and the warm grain next to the walls and the upper surface.

Effect of Geographical Location

The effect of location upon the temperature of stored grain in different parts of the Corn Belt is evident from figure 17. In every case the temperatures in the more northerly locations were lower. This is shown by a comparison in table 1 of the average temperatures for each of the bins taken at 4-month intervals.

Table 1.—*Average temperatures of shelled corn in 2,740-bushel bins*

Location	Latitude	Temperature, ° F.			
		September	December	March	June
East-central Illinois	40°	74	51	39	65
Central Iowa	42°	70	49	36	52
Northeastern South Dakota	45°	60	42	31	43

Corn temperatures and insect infestations observed during March, August, and October 1942 in stored corn at a number of locations are shown in figures 18, 19, and 20. These observations were made about 3 feet below the surface at the bin centers. Grain temperatures shown for March closely approximated the mean air temperatures for the month. In August the grain temperatures were slightly higher and in October considerably higher than the mean air temperatures.

Effect of White Paint on Steel Bins

The use of white paint on the walls and roofs of steel bins shows some promise of being valuable in maintaining lower temperatures of the grain. The effect of white paint has been observed more completely in wheat bins in Kansas than in corn bins. Bins so painted absorb less sun heat than unpainted or dark bins, and grain temperatures in late summer can be kept appreciably lower. White paint is most effective in regions where the sunlight is most intense and continuous. Less benefit may be expected in the eastern part of the Corn Belt than in the southwestern part.

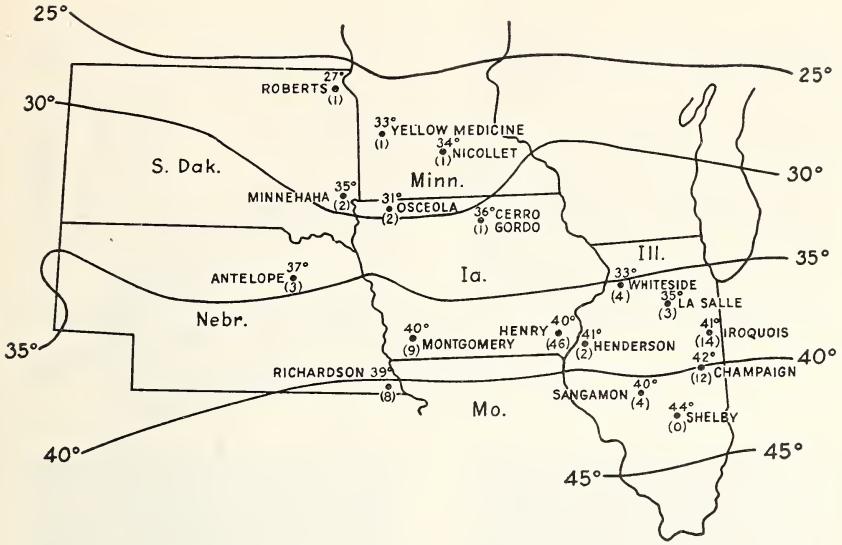


FIGURE 18.—Counties where temperatures were observed in shelled corn stored in steel bins of 2,000- and 2,740-bushel capacity, March 1942. Average of temperatures taken 3 feet below the surface of the grain, in the centers of the bins. Insect infestation shown in parentheses. Mean temperature of air for March shown by isothermal lines.

FIGURE 19.—Counties where temperature was observed in shelled corn stored in steel bins of 2,000- and 2,740-bushel capacity, August 1942. Average of temperatures taken 3 feet below the surface of the grain, in the centers of the bins. Insect infestation shown in parentheses. Mean August temperature of air is shown by isothermal lines.

FIGURE 20.—Counties where temperature was observed in shelled corn stored in steel bins of 2,000- and 2,740-bushel capacity, October 1942. Average of temperatures taken 3 feet below the surface of the grain, in the centers of the bins. Insect infestation shown in parentheses. Mean October temperature of air is shown by isothermal lines.

EFFECT OF METAL VENTILATING TUBES

Steel ventilating tubes as large as 18 inches in diameter placed in the center of the bin have been used experimentally to determine how much the cooling of the corn could be improved. Air was permitted to circulate through these by having the lower end connected to a duct open to the outside air. More rapid cooling of the grain was accomplished in the center of the bin. However, the ventilators also permitted a more rapid warming up in the summer. Merely plugging the ends of these tubes was not effective in retarding the rate of warming. No appreciable benefit was obtained by use of these ventilators.

EFFECT OF INSECT INFESTATION

Whenever a concentration of insects exists in any part of the bin, the heat produced by them will result in a temperature rise. In severe infestations, it has been found to be as high as 105° F. even under conditions of cold weather and well into the winter. A good comparison of temperatures can be obtained from the two bins shown in figure 21, located at New London, in southeastern Iowa. One of these was infested with insects; the other had been turned and cleaned in November 1941. In April 1942 the temperatures were very nearly the same in the two bins, but by the following August temperatures near the center of the infested bin were 100° F., and those in the center of the other bin were between 70° and 80° F. Figure 22 compares the number of insects found in the center of the two bins and also the moisture content and damaged kernels in the upper surface layers.

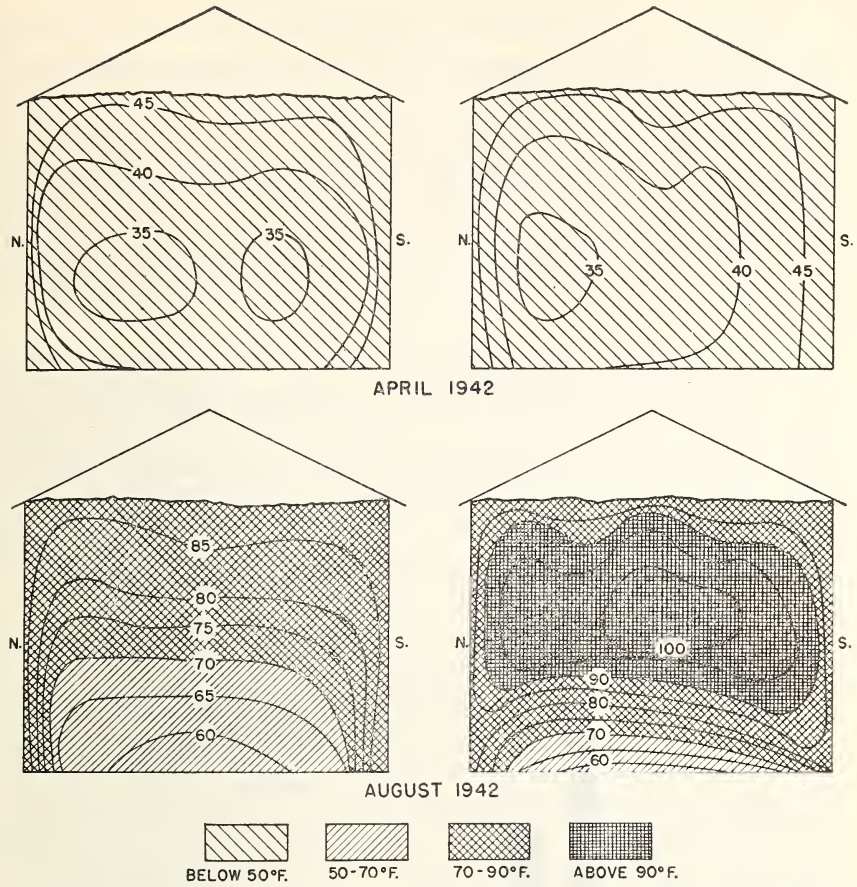


FIGURE 21.—Comparison of corn temperatures in two 2,740-bushel steel bins at New London, southeastern Iowa. (Left) This corn was cleaned in November 1941. There were very few insects in this bin when these temperatures were observed. (Right) The corn in this bin was infested with insects.

INSECT PROBLEMS

The commercial corn area covers a large territory, and the hazards from insect attack vary greatly over the region and from one season to another. Field infestation of corn is seldom serious and then only in the southern part of the area where the Angoumois grain moth occurs. In this region, harvesting of corn is often delayed until late fall or winter, so that field infestations of the moth, the rice weevil, and other insects are destroyed by the cold of killing frosts before the corn is shucked and cribbed.

ANGOUMOIS GRAIN MOTH

In Missouri and the southern half of Illinois and Indiana, the Angoumois grain moth (*Sitotroga cerealella* (Oliv.)) is occasionally troublesome, whereas the northern part of the commercial corn area is

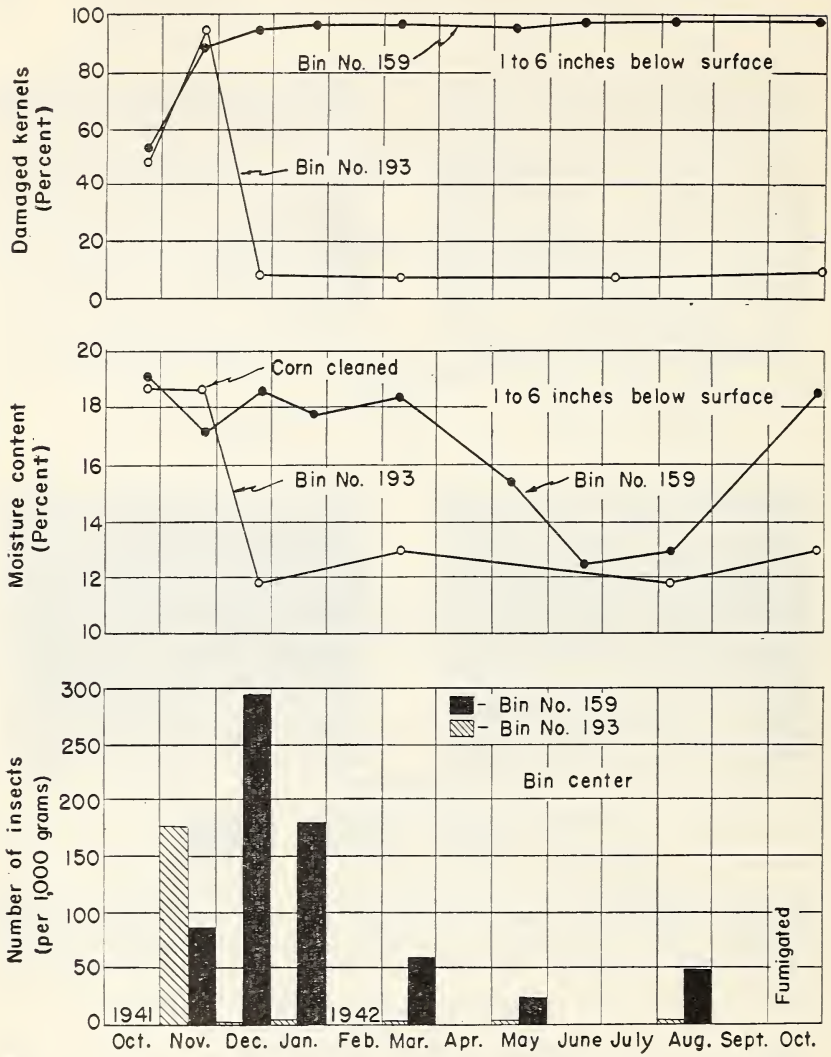


FIGURE 22.—Comparison of insect infestation, moisture content, and damage in two 2,740-bushel steel bins at New London, southeastern Iowa. Bin No. 193 was turned and cleaned in November 1941; bin No. 159 was not disturbed.

beyond the effective range of this insect. Its abundance is influenced directly by the weather and it is never troublesome after a severe winter. Owing to a succession of mild winters in Missouri, Illinois, and Indiana preceding 1939, the Angoumois grain moth increased in numbers and extended its northward range far beyond normal, so that in 1939 infestation of stored ear corn was severe and infestation in the field was common. Severe cold weather in January and February of 1940 destroyed most of the infestation, and since then this insect has not been a problem in the area.

Grain Weevils

The really destructive insect pests of stored grain, those that are capable of breaking through the seed coat to reach the softer endosperm, are seldom troublesome to stored corn in any part of this area. These insects, i. e., the rice weevil (*Sitophilus oryza* (L.)), the granary weevil (*S. granarius* (L.)), and the lesser grain borer (*Rhyzopertha dominica* (F.)), breed rapidly when conditions are just right, but corn stored in small farm storages in the commercial corn area seldom provides conditions favorable for them.

Indian-Meal Moth

The Indian-meal moth (*Plodia interpunctella* (Hbn.)) is found over the entire region. It is not often troublesome, but occasionally it multiplies rapidly and appears in alarming numbers everywhere. Such an outbreak occurred in 1940. A small parasitic wasp (*Microbracon hebetor* (Say)) always accompanies these outbreaks and eventually reduces the moth population to normal. A protective oil spray has been developed that insures positive protection from the attack of this moth.

Bran Beetles and Fungus Beetles

The insects that occur in greatest abundance in stored corn in this region and cause the most concern are known popularly as bran beetles or fungus beetles. They cannot bore through the unbroken seed coat of dry grain and they feed primarily on grain dust, broken kernels, and the molds that grow on damp grain. Some breed in decaying vegetable matter. Others are carried to farm buildings in infested feeds. They fly or crawl to cribs of ear corn when the weather becomes warm and start infestations. When the corn is shelled they may be carried into the bins with it unless the corn is properly cleaned at that time. Storing only clean shelled corn, loaded by machinery that will not crack it, is the best insurance against damage from this class of insects.

Typical of this group are the saw-toothed grain beetle (*Oryzaephilus surinamensis* (L.)), the flat grain beetle (*Laemophloeus minutus* (Oliv.)), the foreign grain beetle (*Ahasverus advena* (Waltl.)), the hairy fungus beetle (*Typhaea stercorea* (L.)), and the red flour beetle (*Tribolium castaneum* (Herbst.)). In 1939 much of the shelled corn was improperly cleaned and considerable breakage occurred because of loading the bins with blowers. As a result, these insects occurred in large numbers at times in all parts of the area. They did not cause much actual damage to normal grain from their feeding, but they caused heating of the corn, and when the surface corn cooled in the fall, water vapor moved from the heating areas to the cool grain where it condensed, causing conditions favorable to mold growth. In severe cases, several inches of surface corn was destroyed by molds.

The Abundant Species

Some species are more resistant to cold than others, and two of these, the flat grain beetle and the saw-toothed grain beetle, were observed

to survive the winter in far greater numbers than the rest. This probably accounts for the fact that both species were always extremely common over the entire area. The saw-toothed grain beetle proved to be the most abundant insect in shelled corn.

In addition to being resistant to cold, this insect reproduces rapidly and the adult beetles are extremely long-lived. The hairy fungus beetle and the foreign grain beetle, two other abundant species, are particularly attracted to damp and moldy grain. They occur in the fields, breeding in a state of nature, and at times migrate to the bins in large numbers. The red flour beetle seldom survives the winter in large numbers, but multiplies rapidly when conditions become favorable. At times it appeared to be more abundant than any other insect. This was particularly the case in Iowa.

Little-Known Insects

Several species of insects not previously considered as pests of stored corn proved to be of considerable importance in this area.

The so-called larger black flour beetle (*Cynaeus angustus* (Lec.)) was first observed as a pest of stored grain in Kansas in 1938. Since that time it has been found infesting shelled corn in all parts of the region. It is resistant to cold, survives the winter well, and in samples taken from representative corn bins over the entire commercial corn area in 1942, it ranked fifth in abundance.

The red-horned grain beetle (*Platydema ruficorne* (Sturm.)) was abundant in Missouri and fairly common in Illinois and Iowa. The black flour beetle (*Tribolium madens* (Charp.)) was common in Iowa, whereas grain mites were more abundant in South Dakota than elsewhere.

FOOD, MOISTURE, AND TEMPERATURE REQUIREMENTS

In order to understand the fluctuations in insect populations in stored corn in the commercial corn area and the reasons for the dominance of different species in different parts of the region, it is necessary to know the food requirements of the various insect pests and the relationship of moisture and temperature to their abundance.

Corn that is cool, dry, and free from grain dust or broken kernels is unfavorable for the development of grain-infesting insects. Bran beetles, of which the red flour beetle and the saw-toothed grain beetle are typical examples, do not lay eggs at 60° F. or below; hence, breeding ceases at that temperature level. They do not breed in clean grain unless the moisture content is 11 percent or above or the temperature is 80° or above. If the corn contains grain dust or broken kernels, they will breed regardless of the moisture content if the temperature is 70° or above.

The rice weevil and the granary weevil breed freely in clean grain, but only when moisture and temperature levels are favorable. Both species will lay a few eggs at 60° F., and immature stages will complete their development at that temperature, although at a much slower rate than at higher temperatures. The adults of the granary weevil become dormant at a temperature of 35° and those of the rice weevil at 45°, and they die in a few weeks if exposed to these tempera-

tures. Grain moisture content is a critical factor. Neither species lives long nor breeds in corn with a moisture content below 9 percent, and little breeding occurs in grain with a moisture content below 11 percent unless the temperature of the grain is abnormally high (90° or above).

CONTROL OF INSECTS ATTACKING STORED CORN

Corn can be stored for years in the commercial corn area without appreciable deterioration or loss from insect attack, provided the few requirements for safe storage are observed. Ear corn is usually stored in slatted cribs where it is exposed to the low temperatures of winter. In average years winter temperatures reduce insect populations to a point where loss from their attack is inconsequential if the normal procedure is followed of using the corn for feed during the ensuing season.

Held-Over Corn Should Be Shelled and Cleaned

Slatted cribs afford no protection to corn from migrating insects, so that with the coming of summer temperatures, when insects are actively flying and crawling, infestation of ear corn is likely to occur. This infestation increases in intensity and importance from the northern to the southern limits of the area.

Corn that is to be stored for an additional year or longer should be shelled as early in the summer as possible and placed in tight bins, preferably of steel. After shelling, the corn should be carefully cleaned, and breakage of the kernels held to a minimum during subsequent loading operations through the use of proper loading machinery. The use of blowers to fill the bins should be avoided. It is perfectly feasible with good cleaning equipment and properly designed elevators to place corn in storage with less than one-half of 1 percent of cracked kernels. This is of great importance, since corn free from grain dust and broken kernels is unattractive to the insects that cause the greatest damage to corn stored in this region.

Protective Oil Sprays

Spraying the surface grain with oil at the rate of 2 quarts for each 100 square feet of surface area is an excellent preventive measure against infestation by the Indian-meal moth and other insects that are likely to migrate to the bins during the summer. The oil should be either technical white or other refined oil of 100 to 200 seconds viscosity (Saybolt, 100° F.) and free from objectionable odor.

Cooling of Grain Prevents Damage

The natural cooling of the corn in the fall and during the following winter and the insulating properties of the grain that prevent a rapid rise in the temperature of the bulk of the corn afford natural protection against damage from insects when the corn is clean and dry.

Insects do not breed actively in stored grain until temperatures exceed 70° F. In the northern portion of the commercial corn area the average temperature of the bulk of the grain rarely reaches a level favorable for active insect development.

Insects Cause Grain to Heat and Spoil

Insects occasionally become established in bins of shelled corn and by their activities create moisture and temperature conditions that are abnormal and, if unchecked, will cause grain spoilage. On the approach of cold weather in the fall, shelled corn that is heating, owing to the presence of colonies of insects, suffers deterioration of the surface layer. Water vapor from the hot grain moves upward and condenses in the colder surface grain. Rotting and spoilage of this surface corn may then occur, although the damage does not appear to extend very far below the surface.

Fumigation of Infested Corn

Fumigation of infested shelled corn in bins will satisfactorily control insect infestations so that the corn can enter the fall and winter in good condition, without danger from excessive surface condensation, and be ready to undergo the natural cooling of winter so necessary for its protection from insect damage during the following spring and summer. Dosages of fumigants found satisfactory for treating corn in steel bins are listed as follows:

Fumigant	*Dosage per 1,000 bushels (gallons)*[1]
Carbon tetrachloride	5
Carbon tetrachloride 4 parts, plus carbon disulfide 1 part[2]	5
Carbon tetrachloride 1 part, plus ethylene dichloride 3 parts[2]	5

[1] In wooden bins the dosages should be increased by 50 percent.
[2] By volume.

To obtain the best results in the fumigation of shelled corn in steel bins, certain fundamental principles should be observed. Bins should have joints calked to make them gastight. Surface areas should be as small as possible compared with the depth, so that a uniform coverage of the surface can be obtained with a relatively small quantity of fumigant and with minimum surface evaporation. The grain surface should be level and at least 6 inches below the top of the side walls. Vapors of the fumigant will then diffuse downward instead of escaping over the side walls. Caking of the surface grain, due to the webbing of weevils or the condensation of moisture, may prevent the uniform penetration of the grain by the vapors of the fumigant. If there is any indication of caking, the surface layer should be broken up by raking to a depth of several inches.

The uniform application of the fumigant to the entire surface of the bin of grain is essential. If possible, application should be made when there is little air movement and during the coolest time of the day.

Precautions

In applying a fumigant to a bin of grain, the fumigator should avoid inhaling any of the vapors, even those from light concentrations, and also avoid spilling the liquid on the clothing, on the shoes, or on any exposed part of the body. The most satisfactory method is to apply the fumigant from the outside of the bin (fig. 23). An inexpensive bucket sprayer or a large power sprayer will be found satisfactory to spray the fumigant over the surface of the corn in a coarse stream.

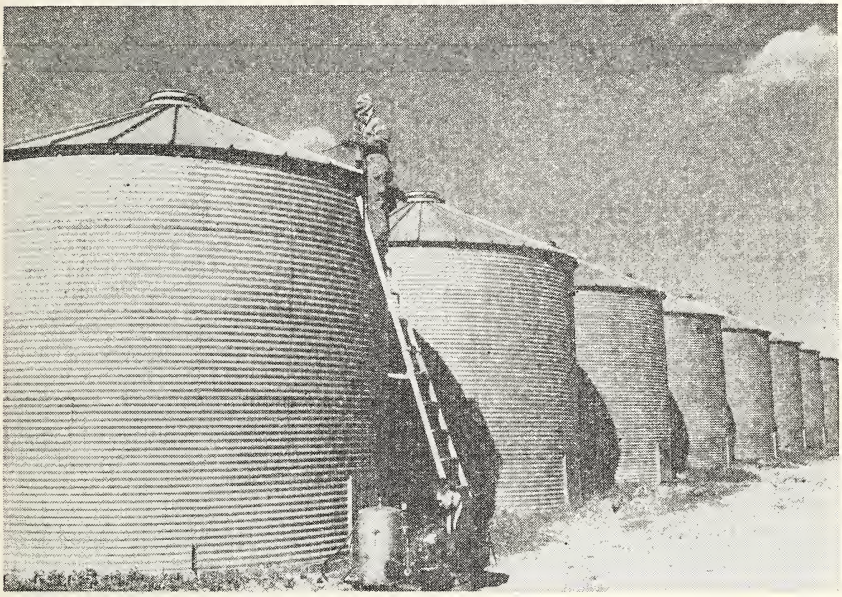


Figure 23.—Applying the ethylene dichloride-carbon tetrachloride mixture with a hand-operated sprayer. A uniform distribution of the fumigant over the surface of the grain can be obtained in this way without exposing the operator to strong concentrations of the gas. The operator should, however, wear a gas mask for protection from the vapors.

It is unwise to apply the fumigant with a sprinkling can or by any other device which necessitates entering the bin for the purpose, since the vapors of all fumigants have an anesthetic action when breathed and fumigators exposed to their vapors for any appreciable period are likely to be made seriously ill, even if not overcome. A gas mask provided with a full facepiece and a canister approved by the United States Bureau of Mines for protection against vapors of the fumigant used should always be worn by anyone who is exposed to vapors of fumigants. Canisters should be changed after a total of 30 minutes of actual use whether continuous or intermittent, as the absorbent materials become saturated with the vapors of the fumigant and will no longer afford protection. A record of use should be kept on the canister itself.

APPENDIX

Bin Sites

Sites should be well drained to prevent surface water from accumulating and standing around the bin bases. On a number of poorly drained sites, water from heavy rains or floods caused serious spoilage in the lower parts of bins. All bins should be arranged with a definite plan for loading, unloading, and, if necessary, transferring grain within the site. The type of equipment to be used in handling the grain should be considered in selecting and laying out the site, as this will influence the spacing and arrangement of the bins. Consideration should be given to future erection of additional bins and sufficient room should be provided for the planned spacing of such bins.

Some suggested spacings are given in table 2 for several bin types and sizes. Varying conditions will affect these widths, but the table provides some approximate dimensions useful in planning for bin site lay-outs and suitable elevator lengths. The width of driveway will be influenced by the length and type of elevator used.

Table 2 shows only the type of portable elevator which uses some form of feed hopper. Some of the newer auger types of grain elevators unload directly from a truck or wagon (fig. 14). Such an arrangement will affect the amount of space needed. The length of elevator will be influenced by the bin heights and by the point at which the grain is emptied into the bins. Elevating into the bins at or near the roof peak requires a longer elevator than elevating only to the top of the side walls but saves much of the labor required to shovel back the grain when a shorter elevator is used.

Elevators with flights running overshot are generally limited to an operating angle not greater than 45°. Elevators with undershot flights may be operated at angles as great as 65° to 70°. Operating flight elevators at steep angles, however, reduces the capacity materially. For example, increasing the slope from 40° to 60° may reduce the capacity of these elevators for elevating shelled corn by as much as 30 percent. This point needs consideration when planning bin sites and the purchase of elevating equipment. The space required for portable elevators is shown in figure 24.

Several arrangements for circular and rectangular bins are shown in figure 25. One arrangement shows two rows placed close together with sufficient space between them and additional rows for manipulation of elevators (fig. 25, *A*). Several of the suggested elevator lengths permit filling at or near the roof peak. Under these conditions, grain can be moved from a bin in one row to the bin directly opposite in the other row with the same elevator. The suggested elevator lengths and spacings for bins in the row will also permit the transfer of grain between bins in a row.

The arrangement in figure 25, *B*, permits moving of grain in either row to one of two opposite bins in the other row. When filling bins from trucks it is generally necessary to set the elevator as shown.

Suggested arrangements and spacings for rectangular bins are shown in figure 25, *C*.

TABLE 2.—*Suggested spacings for several bin types and sizes for various lengths of portable grain elevators*

Type of bin	Radius of bin	Height of bin		Portable elevator			Spacing for bin rows and bins within the row (dimensions refer to fig. 25, p. 35)							Filling opening
		Side wall	Overall	Length	Working angle	Space required [1]	A	B	C [2]	D	E	F	G [2]	
	Feet	*Feet*	*Feet*	*Feet*	*Degrees*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	
2,740-bu. circular, steel	9	13½	17½	34	36	20	22–28	22	48	38–40	28–30	-----	-----	Near roof peak.
				30	45	14	22	22	42	-----	-----	-----	-----	Do.
				20	47	12–14	22	22	40–42	-----	-----	-----	-----	Roof manhole.
2,000-bu. circular, steel	9	11	15	30	36	16	22–26	22	44	32–34	26–28	-----	-----	Near roof peak.
				24	36	16	24–26	22	44	-----	-----	-----	-----	Roof manhole.
				20	45	11	22	22	38–40	-----	-----	-----	-----	Do.
2,800-bu. rectangular, wood (gable roof)	7	10	14	28	36	15	-----	-----	-----	-----	-----	6–12	38–40	Near roof peak.
				24	45	10–12	-----	-----	-----	-----	-----	6–12	34–36	Do.
				20	45	8–10	-----	-----	-----	-----	-----	6–12	32–34	Gable-end doors.
1,600-bu. rectangular wood (gable roof)	6	10	14	28	30	16–18	-----	-----	-----	-----	-----	6–12	38–40	Near roof peak.
				24	40	12	-----	-----	-----	-----	-----	6–12	34–36	Gable-end doors.
				20	45	8	-----	-----	-----	-----	-----	6–12	30–32	Do.
1,000-bu. rectangular, wood (shed roof)	5	Front 8; rear 6	8	20	36	12	-----	-----	-----	-----	-----	6–12	34	Roof door.
				16	30	14	-----	-----	-----	-----	-----	6–12	34	Front-wall door.

[1] Measured from bin side wall; no allowance for hopper and working space. (See fig. 24, p. 34.)
[2] 10 feet additional space has been allowed for hopper and working space.

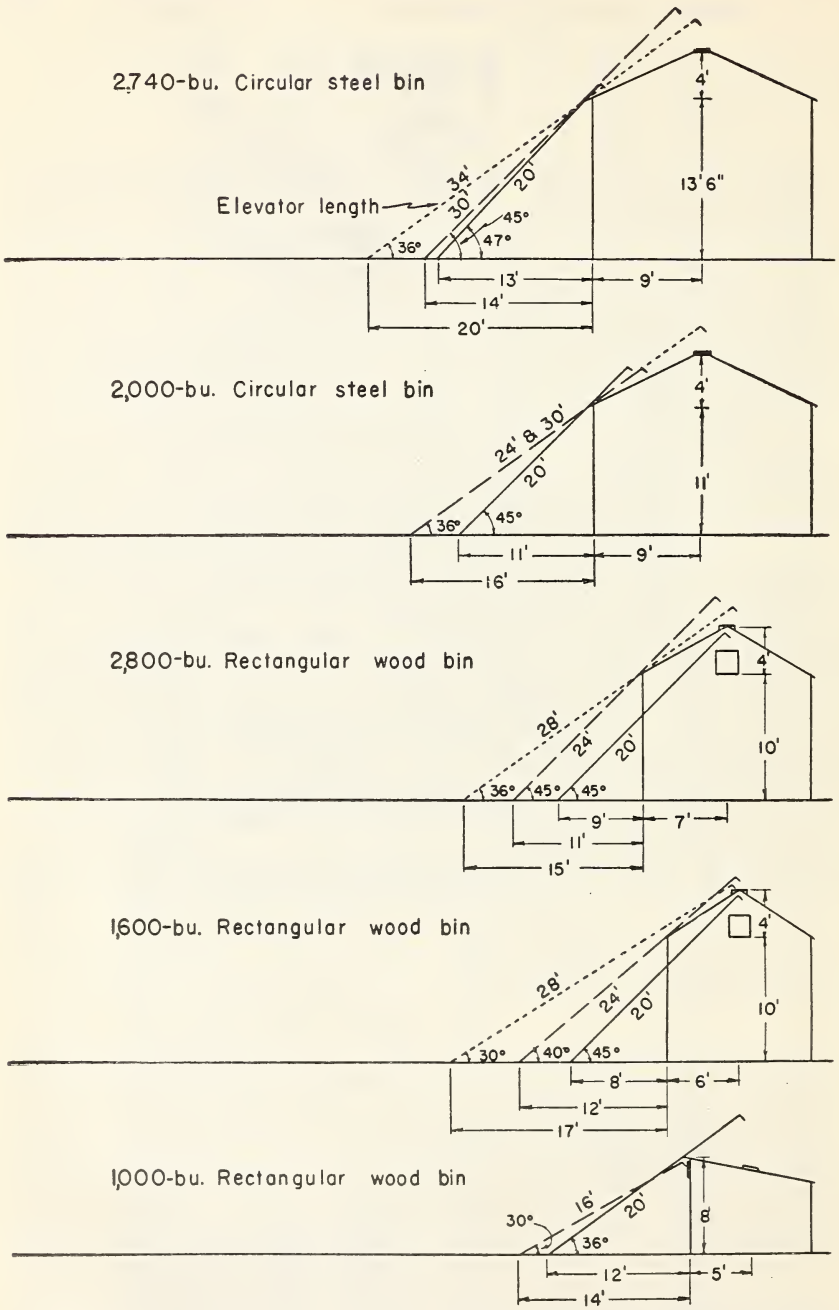
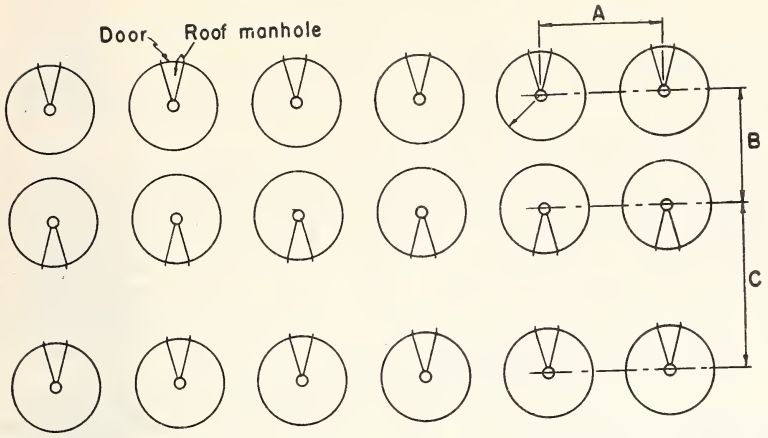
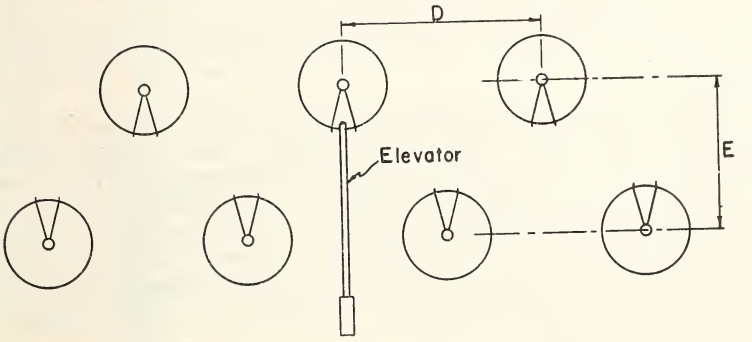


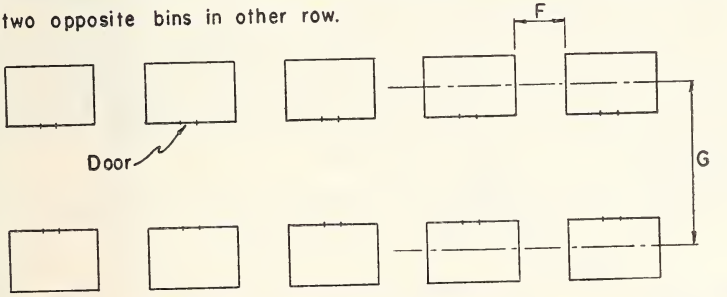
FIGURE 24.—Spaces required for portable elevators of various lengths when used in filling bins of different types and sizes. In table 2 an additional 10 feet is allowed for hopper and working space.



A, Compact arrangement of bins in two rows with driveway wide enough to permit easy manipulation of elevators when filling.



B, Arrangement of bins to permit moving of grain in bin in either row to one of two opposite bins in other row.



C, Arrangement and spacing of rectangular bins.

FIGURE 25.—Arrangement and spacing of bins. Refer to table 2 for suggested spacings and lengths of portable elevators.

Turning and Cleaning During Long-Time Storage

Cleaning should be done at the time the corn is shelled and put into storage. There should be no need to reclean corn if proper shelling and storage practices are followed.

A considerable amount of Government-owned shelled corn in steel bins was turned and cleaned after one or more years of storage because it was not properly cleaned before storing. This cleaning removed a large portion of the cracked corn and foreign material, and insect infestations were reduced to a point where little further trouble was experienced from that source. The corn was also put in a better condition for fumigation, if needed. The cost of turning and cleaning varied from ½ to 1 cent per bushel. Much of this expense would have been avoided by cleaning at the time of shelling.

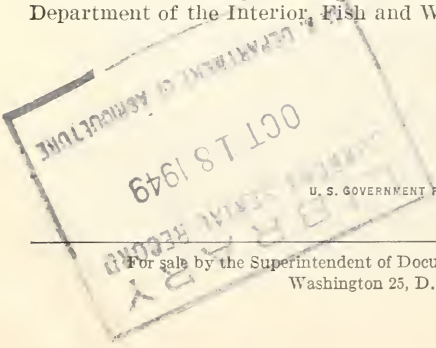
Several different types of cleaning equipment were developed and used. These varied considerably in construction and arrangement, but may be classed as follows: (1) Gravity screens, (2) agitated screens with or without air blast, and (3) corn shellers adapted for cleaning purposes.

Gravity screens were satisfactory. Corn-sheller cleaners did not reduce the cracked corn and foreign material to as low a percentage as some of the other types. Nearly all of the cleaners, however, reduced the cracked corn and foreign material to less than one-half of 1 percent.

One or two portable elevators were required for the turning operations, depending upon the type of cleaner used. There are some difficulties encountered when turning and cleaning shelled corn stored at a large site. It is generally necessary to turn all bins on a site in sequence, regardless of need, or to incur the additional expense of hauling the cleaned corn to another bin. Heavy snow or mud often makes it impossible to operate the equipment. Large quantities of insect-infested screenings present a problem of prompt disposal to prevent reinfestation.

Necessity for cleaning shelled corn after storage can almost always be avoided. Proper crib construction and rat control practices [4] prevent most of the rat damage and reduce the amount of material which must be removed by cleaning. Proper adjustment and operation of shellers result in clean corn. Too rapid feeding of shellers should be avoided. Screenings should not be cleaned up under the sheller and mixed with shelled corn, nor fed through the sheller in quantities too large to permit complete cleaning.

[4] See "Rat Proofing Buildings and Premises," Conservation Bulletin 19, U. S. Department of the Interior, Fish and Wildlife Service.



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